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CLXVI.

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REMINISCENCES AND EXPERIENCES OF EARLY ENGINEERING OPERATIONS ON RAILROADS, WITH ESPECIAL REFERENCE TO STEEP INCLINES.

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Read May 1st, 1878.

My first acquaintance with railroad inclined planes began in Pennsylvania, at Mauch Chunk, on the River Lehigh, in the spring of 1827, whither I had been sent by Canvass White, chief engineer, as a young assistant to go upon the survey and construction of the Lehigh Canal. At that time Josiah White, of Philadelphia, was the acting manager of the Lehigh Coal and Navigation Company, and all the extensive works in and around Mauch Chunk were under his special charge. Erskine Hazard, his former partner, and one of the most active directors of the company, had previously, in 1826, visited Europe and examined the coal operations in England and Wales, and had also taken note of the very limited railroad experience of that day in England.

Having been personally familiar with the operations of these gentlemen during the years 1827–'28 and '29, and well acquainted with Josiah White, who then resided at Mauch Chunk, which was my engineering home for three years, I here take occasion to record that Mr. White was one of the most remarkable men of that period. His natural ingenuity was almost marvelous; which, joined to intelligent foresight and the most untiring energy and perseverance, enabled him to overcome engineering difficulties almost as quickly as they were encountered.

At the period of my arrival in Mauch Chunk Mr. White was engaged in changing the system of transporting coal from the summit of the Broad-Top Mountain (from the 60 feet thick bed of anthracite coal) by substituting a railroad for the turnpike. The turnpike was an admirable road, and so well graded that a large portion of it was used for the bed of the railroad then being laid. It was a gravity railroad, having a gauge of 3 feet 6 inches and a length of 9 miles. It terminated at the head of the inclined plane at Mauch Chunk, which was then in use for letting down coal to the "arks," in which it was conveyed by the then existing *descending* navigation on the Lehigh and Delaware rivers to the City of Philadelphia. On the Lehigh, Messrs. White and Hazard had constructed an artificial navigation, consisting of dams and movable gates, and the "arks" were *sluiced* from pool to pool for 47 miles, to Easton, on the Delaware.

While waiting for others of our engineer corps to arrive, and at intervals afterward, I saw much of this first American coal and passenger railroad laid down, and rode upon the first passenger train of very small cars which passed over it. I also paid particular attention to the working of the inclined plane. Having long ago unfortunately lost my notes and drawings of this early railroad, its cars, machinery, etc., as used in 1827, I can now only refer to them in a somewhat general way from recollection. The inclined plane had an elevation of about 200 feet. It was quite steep, especially at the ends, but flatter near the middle, conforming measurably to the slope of the irregular side hill. Its length was, I think, about three or four times its height. It had a double track passing place for the cars near the middle, a single track at each end, and was worked by the gravity of the loaded car, which, in descending, turned a large drum at the head of the plane, around which the rope was wound which pulled up the empty car, the motion being regulated by a friction brake.

During the summer or fall of 1827 Mr. White constructed another experimental inclined plane, upon a novel principle. It was of full size, and was worked by water power obtained from the creek which flowed through the narrow valley near its foot. The track itself was an ordinary 3 feet 6 inch gauge; but between the rails there were three movable wooden stringers the whole length of the plane, having upon their upper faces an iron rack. These movable bars were geared to the water-wheel so that they worked back and forth, alternately. To the rear end of the car three hanging bars of iron were attached, which touched and pressed their lower extremities against the notches or rack on the movable bars. When the water-wheel was set in motion, the car was pushed up the plane, in a rather jerking manner; the upward movement of each of the three bars progging the car along. I assisted in some of the experiments made with that very peculiar inclined plane. It certainly did fairly propel loaded cars up the plane; but the principle was not afterward applied at any time in the regular business of the company. All the old railroads and planes which existed at and near Mauch Chunk fifty years ago, the period referred to, have long been superseded by modern tracks of standard or 4 feet 8½ inch gauge for locomotives, and improved inclined plane gravity roads and switch-backs of the present era, which constitute such striking features of that coal region now. In 1827 the coal business of the United States and railroading were yet in their infancy.

In 1831 I was appointed senior principal assistant engineer under my friend and preceptor, Sylvester Welch, chief engineer on the Allegheny Portage Railroad in Pennsylvania. The other principal assistants were my lifelong friends, Solomon W. Roberts and Edward Miller, the latter since deceased, after a well-spent life. In the spring of that season I surveyed and located eight of the ten inclined planes, and afterward superintended their construction, namely, Nos. 3, 4 and 5 on the western, and 6, 7, 8, 9 and 10 on the eastern slope of the Allegheny Mountain.

Mr. S. W. Roberts, who had charge of the western half of the railroad, surveyed, located and superintended the construction of Nos. 1 and 2, the two planes on that division; which division included the first railroad tunnel in the United States. Mr. Edward Miller's duties began a little later, and they were chiefly in the main office with Mr. Welch, arranging the plans and drawings for the stationary engines and machinery of the ten planes.

The inclination of these planes varied from about 8 to 10¼ per cent. except No. 9, which was 7¼ per cent. The longest, No. 8, being 3,116 feet (including a very short curve at the top, and a curve 200 feet long at the bottom). It had a total rise of 308 feet, the straight portion having a rise of 10¼ feet per 100, or an angle of 5° 51′ 9″. The old Philadelphia and Pittsburgh turnpike, which crossed the mountain, in sight, and close by, had upon it grades of six degrees, and I made it a point, in establishing the inclination of the steepest plane on the railroad, that it should be flatter than the turnpike grade, and the fact was stated in our published reports following, for the information of the Legislature and the public. At that day there was a dread in the public mind in regard to inclined planes.

In 1832, in company with Chief Engineer Welch, I rode across the country on horseback, from the Allegheny Mountain, and visited the inclined planes on the Morris Canal, in New Jersey, and those on the Carbondale and Honesdale Railroad in Northeastern Pennsylvania, both being then new, and made notes and drawings to aid in the studies of the details of our mountain inclines. Mr. Archbald* was then chief engineer and manager of the Carbondale and Honesdale Railroad, upon which the inclined planes, with stationary engines at the head, had recently been put in operation.

Several plans were proposed for working the planes; the one adopted was with a double track railroad and an endless rope, worked by a stationary engine at the head of the plane.

No survey had been ordered by the State for a graded railroad without planes over the mountain. There had been, however, a survey made across the Allegheny Mountain, between Hollidaysburg and Johnstown, a distance of about 37 miles, in 1826, having partly in view a low grade *macadamized* road—the "macadamized" road being then a new thing in England. George T. Olmstead, under Canvass White, Chief Engineer, had charge of the survey; John T. Young, of New York State, was one of the levelers; F. H. Petrie, of Portland, Maine, was compass man; and A. B. Warford and W. Milnor Roberts were the rodmen.

Permit me in this place to mention the fact that Messrs. Clarke and Holgate made a survey in 1824, for a continuous canal through the Allegheny Mountain. In order to insure a sufficient natural supply of water they proposed a tunnel *four miles* in length. At that day such a

* The father of James Archbald, member of this Society.

tunnel became a subject of ridicule, and the canal project through the mountain was dropped. Yet Messrs. Clarke and Holgate were, like other bold projectors, merely in advance of the age.

The real impediment now, as it was then, is the fact that the *canal* would be frozen up, in this latitude, during at least one-third of the year. There is also another very important obstacle, the large amount of lockage—even with a four-mile tunnel.

In the State of Pennsylvania, a canal system, in preference to a railroad system, had been deliberately adopted in the Legislative Session of 1825–26, and Canvass White, then Chief Engineer of the Union Canal,* and prior to that one of the earliest engineers of the New York Erie Canal, was appointed to make the surveys between the Susquehanna river, at Duncan's Island, above Harrisburg, to the Ohio River, at Pittsburgh, by way of the Juniata river on the eastern side of the Alleghenies, and on the western side via the Conemaugh and Kiskiminitis rivers to the Allegheny, and down that river to its junction with the Monongahela, at the head of the Ohio, at Pittsburgh.

The State canals were begun in 1826 and 1827, but nothing was decided as to the mode of crossing the mountain for several years.

In 1829 preliminary surveys were authorized by the Legislature, and were made under the direction of Moncure Robinson,† for a railroad over the mountain, with inclined planes, between the terminal points of the canals—Hollidaysburg on the eastern and Johnstown on the western side.

In 1830 another set of surveys was made under the direction of Col. S. H. Long, U. S. A., and Major John Wilson—the latter was afterward Chief Engineer of the State Railroad between Philadelphia and Columbia.

These surveys indicated the employment of eleven inclined planes. Col. Long proposed several curved planes; but Mr. Robinson favored straight planes, even although some of them might cost considerably more.

After a partial examination of the grounds, in 1831, I suggested that it might be practicable to locate the line with five inclines on each side of the summit, all straight (dispensing with one plane), and Mr. Welch

* The Union Canal of Pennsylvania, 81 miles long, extends from Reading, on the Schuylkill river, to Middletown, at the Susquehanna river.

† Mr. Robinson, who is still living, was one of the earliest members of this Society.

instructed me to so locate them, if the cost should not prove too great. By the employment of short levels between Nos. 6 and 7, and 7 and 8, and making plane No. 8 considerably longer than the others, and with the maximum inclination of 10½ feet per 100 feet, the location with ten instead of eleven inclines, all of them straight, was finally effected. At that early period in railroading the crossing of the Allegheny Mountain was regarded as quite formidable. Had the Legislature authorized surveys to determine whether a regularly graded road throughout or an inclined plane road should be adopted, it is possible that a road with inclined planes might never have been built there; but the general plan was, as already intimated, settled by the Legislature, in advance. A graded line would have been only about ten miles longer, even on a grade of 52 $\frac{8}{10}$ feet per mile, or about 47 instead of 37 miles.

It was not however, certain, when the Allegheny Portage Railroad was located (in 1831), that locomotives would be used upon it. After very careful surveys, at my earnest solicitation, a grade of 52 $\frac{8}{10}$ feet per mile for about three miles, on a straight track, below plane No 10, was adopted, in lieu of a line with numerous curves on a grade of 42 $\frac{84}{100}$ feet per mile. To bring the grade down to 52 $\frac{8}{10}$ feet, I had to sink it, at the foot of the plane, ten feet below the bed of the creek, put a culvert for the stream under the inclined plane, and excavate an entirely new creek channel for a considerable distance. It answered perfectly.

At that period there was a general impression among English engineers, assented to readily by our still less experienced American engineers, that locomotives could do very little work on grades above thirty feet per mile. There were then inclines of only 50 feet per mile in England worked with ropes and stationary machinery. Thirty feet per mile was the maximum adopted by Major Wilson,* the Pennsylvania State Chief Engineer, who located the first State railroad between Philadelphia and Columbia, 82 miles. Columbia is a town on the Susquehanna river, 12 miles west of Lancaster. The adoption of a thirty feet maximum gradient involved the construction of two inclined planes, one near Philadelphia, called the "*Schuylkill Inclined Plane,*" the other at Columbia, called the "*Columbia Inclined Plane.*" They had inclinations of about 7 feet per one hundred feet rise. The Schuylkill plane was over half a mile in length (2,805 feet, with a rise of 187 feet). The Columbia plane was considerably less (1,900 feet, with a rise

* The father of W. Hasell Wilson.

of 90 feet). The intermediate line, about 78 miles, was located with the maximum grade of 30 feet per mile, and with numerous curves of 10° or over, deflection per 100 feet. The summit cut at the "Gap," east of Lancaster, proved to be so difficult and costly, on account of quicksand, that it was ultimately laid on a grade of about 44 feet per mile, and I believe it so remains.

The continuation of this State railroad from Lancaster to Harrisburg, 37 miles, was located by me as Chief Engineer in 1835, for the "Harrisburg, Portsmouth, Mt. Joy and Lancaster Railroad Company." I adopted a maximum gradient of 0.75, or $39\frac{6}{10}$ feet per mile, which was strictly adhered to in passing the summit, near Elizabethtown, Lancaster County. Some years afterward, when the Pennsylvania Railroad Company became the purchaser of the State improvements, they leased for ninety-nine years this Harrisburg and Lancaster line, and it now constitutes a link of their main line between Philadelphia and Pittsburgh.

In the session of 1847–48, the Legislature of Pennsylvania appointed me the engineer to survey and report upon a route for *avoiding the Schuylkill Inclined Plane*. At the time of this special appointment I was engaged in building the Sandy and Beaver Canal, in the State of Ohio, which was nearly completed. During the summer and fall of 1848 I made the survey and report upon the avoidance of this inclined plane, and recommended substantially the line upon which the new road (now part of the Pennsylvania Railroad) was soon after constructed.* I advised the sale of about three miles of the old railroad between the inclined plane and Broad street, Philadelphia, to the Reading Railroad Company, which was made. I also advised the purchase by the State of a large lot of ground on the west side of the Schuylkill river for terminal purposes; for this I was sharply censured by some critics for my extravagant assumption that so large an area could be needed. In those days they did not build terminal stations and round-houses, etc., by the acre. It would hardly answer now to confine the Philadelphia terminus of the Pennsylvania Railroad to twenty-five acres.

To return from this partial digression to the Allegheny Mountain Inclined Planes: the Mountain Railroad was finished, and a train of cars, drawn by horses on the levels, was passed over all the planes on the

* It may be here mentioned that the *Columbia Inclined Plane* was also avoided about the same time upon a route surveyed by W. H. Huffnagel, C. E., Assistant, so that about 1850 the State Railroad between Philadelphia and Columbia was freed from inclined planes and left with maximum grade of 45 feet per mile, and a general limit of 30 feet per mile.

21st of November, 1833. A committee of the Board of Trade of Philadelphia had gone out westward some time before, and we had promised to give them a pioneer ride over the Mountain Railroad on their return. We worked very hard, and barely accomplished it, much to their gratification. The train of new freight cars had been put upon the road by David Leech. They started in the morning from Johnstown, and about ten o'clock that night, in the midst of a snow storm, our friends, after passing over all the planes, were delivered safely in Hollidaysburg. The railroad and the canals with which it connected were then closed for the season. In the spring of 1834 the Allegheny Portage Railroad was regularly "opened to the public." It was so literally; for any persons who chose could put cars on the track, and haul them, with their own horses, from either end to the foot of the first plane, and on the levels between the planes; the State merely transporting the cars up and down the inclines, by means of the stationary engines at the head. This system, as the number of cars and of persons using the road increased, soon became exceedingly troublesome. I had the general charge and management of the running of the road, and of the inspection, weighing, numbering and registering of the cars during the season of 1834, as well as the general superintendence of the working of the ten inclined planes; so that I was almost constantly on the road.*

At the same time, the State having so determined, a permanent second track was being laid throughout the entire 37 miles, excepting upon the planes, where the track had been laid double in the first instance. This work, which was an arduous duty, was under the immediate charge of S. W. Roberts, Principal Assistant Engineer. A large number of cast-iron chairs were required for this road. They weighed from 13 to 14 lbs. each. The rail (excepting on the planes, where wooden stringers and flat bars were laid), was of the "edge" pattern, weighing 39 lbs. per yard. Added to my duties of that season was that of superintending the manufacture of the cast-iron chairs, and the delivery and acceptance of the chairs and rails, etc. The work of assistant engineers in those primitive days was only limited by their capacity. In the first track, stone-blocks 2 feet square and 1 foot thick were bedded on broken stone laid 1 foot deep, the blocks set at intervals of one yard from centre to

* During the season of 1834, I had the pleasure to escort M. de Chevalier, of France, in company with Moncure Robinson, over the road. I also escorted General Bernard and his family at another time. General Bernard said to me that the Portage Railroad was second only to the passage of the Simplon in boldness and magnitude. Where are its glories now?

centre, supported the chairs, the chairs being fastened thereon by spikes driven through locust plugs 1½ inches in diameter let into holes 6 inches deep, previously drilled in the stone-blocks. The rails were held in place by wrought-iron wedges.

In the second track, in some places, stone cross ties 7 feet long were laid, at intervals of one yard from centre to centre, in lieu of the two separate blocks used in the first track. This, being bedded on a foot in depth of broken stone, made, as may be imagined, not only a solid, but a too *rigid* road. It may as well here be stated that in a few years these stone supports were superseded by wooden cross-ties.

The delivery of a large portion of the materials along the line for the second track, and for the duplicate stationary engines at the planes, added to the daily increasing general transportation of freight and passengers on the single track, demanded almost constant attendance on the line, as questions daily arose, in the use of the road by various independent parties, which I was daily called upon to settle. The "telegraph" was not yet born; and railroad experience was still a thing in embryo. The gigantic railroading of the present day had not then an existence even in dreams. Neither the "General Manager" nor the "Receiver," had yet been invented.

The machinery which worked the inclined planes was simple. An endless rope of from three to three and a half inches in diameter (for different planes) passed around a large horizontal, double grooved, fixed wheel at the head of the plane, and thence, supported on numerous sheaves, set in the middle of the tracks, to the foot, and around a *movable*, smaller horizontal grooved wheel below the foot of the plane. The lower wheel was attached to a carriage, so that when necessary, the slack of the rope, from stretching, was readily taken up. The stationary engines had double cylinders, of sizes proportioned to the particular plane. They were called from thirty to forty horse-power each. There were two systems of brakes for restraining the velocity of the rope and stopping the attached cars at pleasure; one, the ordinary iron-band friction-brake; the other, a water cylinder, having a regulating valve, which, when partly closed, checked the speed in proportion to the space left open for the water to rush through, which, when entirely closed, stopped all motion. I sometimes let a train (of four four-wheeled cars) down a plane by the water-brake alone, without using steam; and occasionally allowed a descending loaded train to bring up cars on the opposite track by their gravity, reg-

ulating the motion without the aid of steam, by the water-brake. The engines were high pressure, and were built at Pittsburgh and Blairsville. The ropes first used were hempen; though some grass ropes were put on during the year, which answered tolerably well.*

The freight cars were all four-wheeled, weighing from three to three and a half net tons each, or six thousand to seven thousand pounds. The passenger cars first used were of the primitive formation, designed and put upon the road by Mr. Lot Dixon, one of my assistant engineers. They seated comfortably twenty-five persons inside, and, like the interior of a modern street car, accommodated an indefinite number outside. We frequently "put the passenger cars through" over the 37 miles, including the passage of the ten inclined planes, in about five hours, and sometimes, under the most favorable circumstances, in four hours. The ordinary running time depended somewhat upon the extent of the delays caused by accumulations of freight cars. Upon one occasion, late in the season, I carried the business of the road, at Plane No. 10, when the stationary engine was out of order, by means of one of William Norris' locomotives, which weighed, I think, about twelve tons, by running it empty up the plane, and then attaching it to the endless rope on the descending track, putting on steam, and thus pulling up a train on the ascending track; then, detaching the locomotive at the foot of the plane, and again running it up. The same or a similar locomotive was run, by its own steam, up all the planes, including the steepest on the road, namely, 10¼ feet per 100 (541 feet per mile) for 3,100 feet of length, the total rise being 308 feet. The inclination of Plane No. 10 was 8¼ feet per 100, or 436 feet per mile; its length a little less than half a mile (2,295 feet). At the time the locomotive was run up the grade of 541 feet per mile, my opinion was that for a locomotive of that construction (with two drivers), 10¼ feet per hundred was *near* the limit at which it could be run up by its own steam power with only its own adhesion.

The grades on the so called "levels" between the inclined planes were very light, generally 0.40 per 100 feet, or 21.12 feet per mile.

At the planes the cars were attached (very quickly) to the main ropes by means of loose stopper-ropes—two to each car; the men specially employed for this duty soon acquired wonderful dexterity in hitching and unhitching; so that when there was no obstruction from accumula-

* A few years afterward, wire ropes, manufactured by my friend, John A. Roebling, C. E., were substituted, and were found to be in the long run safer and more economical than the hempen ropes.

tion of cars a train of four cars was passed up or down a plane with very little detention. In the first use of the planes occasionally a defective "hitch" led to the running away of cars, resulting in considerable damage. The Chief Engineer, Mr. Welch, suggested to me the employment of a small four-wheeled safety car, having a horizontal iron shoe, upon which the wheels of an accidentally detached car should be stopped, the car by its weight on the shoe producing sufficient friction on the rail to stop it on the plane. Upon reflection, it occurred to me that by using only two small wheels, with a bent axle, high enough to pass above the main rope, a very much lighter and much more easily handled car could be obtained. I accordingly made the drawings and had one built under my own superintendence in Johnstown. It was then tested on Plane No. 1 by allowing a car loaded with pig-iron to strike upon the shoes after a free run of some feet, when the car was at once safely stopped. This style of safety car was immediately adopted, and they were soon used, invariably in front of the descending and in rear of the ascending trains. The general plan was also copied and introduced on the other State inclined planes, at Columbia, and near Philadelphia. Accident from the breaking of the hitches or of the main rope were thus rendered comparatively harmless.

There was an incident at Plane No. 10, the lowest on the eastern side of the mountain, which may not be uninteresting, though it was only a troublesome *bore* at the time. The head of the plane was a very dry mountain spur, nearly two hundred feet above Blair's Gap Run, a mountain stream flowing nearly parallel with the spur upon which the inclined plane was built. The geological formation of the spur is a very compact dry slate rock, pitching into the hill at an angle of some thirty degrees. Flowing water could not be brought to this plane for the use of the stationary engines at its head short of laying pipes for nearly two and a half miles, and the conveyance of water by tanks up the plane becoming troublesome, a well was sunk a few feet deep at the head of the plane, and then a five-inch bore hole was started and sunk more than two hundred feet, that is, some feet below the level of the creek, without meeting with a drop of water. I then urged the laying of wooden pipes (of young hemlock) from a point on the creek high enough to allow the water to flow by gravity to the head of the plane. The chief engineer authorized it and it was done immediately ; but he also required the boring at the well to be continued, and it was continued to the depth of between seven

and eight hundred feet without encountering any water, excepting what we poured in at the top to assist the drilling. It was then abandoned. It affords good geological proof that the compact slate rock continues to that depth; and also that there is such a thing as an absolutely dry well, nearly eight hundred feet deep.*

In 1835, '36 and '37, being engaged in the building of the Harrisburg and Lancaster and the Cumberland Valley Railroads, in Eastern Pennsylvania, I had no direct connection with inclined planes, excepting that, in 1836, my friend William Norris invited me to meet a number of gentlemen to witness a promised performance of one of his locomotives, namely, to take a passenger car (eight-wheeled†), with fifty persons in it, up the Schuylkill Inclined Plane, at the rate of ten miles an hour. The first morning this experiment was to be tried it was found that some malicious or humorous individual had greased the track, which prevented the test for that time, but shortly after, when the grease had been removed, his locomotive actually performed as he had promised. A careful record of the performance was printed in a quarto pamphlet at the time, but I have not seen it for a great many years. One of the passengers was an English officer, who (as Mr. Norris afterward told me), when he related the occurrence in England, was not credited, the railroad *savants* on the other side having already "decided" that the limit of locomotive possibilities stopped very far short of 422 feet per mile rise, which was the grade of the Schuylkill Plane. The length of this plane was about half a mile.

In 1836 Mr. William Norris built several locomotives for me, to be

* On the first of January, 1835, an exceptionally cold day, I rode on horseback, in company with Chief Engineer Welch, from Johnstown to Blairsville, to meet James Clarke, President of the Board of Canal Commissioners, for the purpose of resigning my position on the Allegheny Portage Railroad, and of bidding him farewell. I had no further connection with that road till the winter of 1838-39, when the Board of Canal Commissioners appointed me their engineer to examine and report upon its condition, and to estimate the cost of putting it in thorough repair, which I did in the winter of 1839. The wire-ropes put in by Mr. Roebling were then in use, and were considered more economical than the hempen ropes. The same rails which had been laid down in 1833 were still in very good order, and the business had very largely increased. The Pennsylvania Railroad had not yet been seriously thought of.

† Passenger cars with eight wheels had not then been long in use. I think it was in 1835 that I went with Mr. Norris to Mr. Imlay's car shop, on Bush Hill, Philadelphia, to examine the first eight-wheeled passenger car, as I understood. I pronounced it just the thing for the Columbia Railroad, which abounded in curves. Mr. Imlay remarked that I was the first civil engineer who had said it would succeed. It was soon after placed upon the Columbia Railroad. I had the honor to have a similar car, which was placed on the road the same year, named after me by the authorities in charge of the road, without my knowledge or saying by your leave. Eight-wheeled passenger cars, in those days, were regarded as grand affairs.

used on the Cumberland Valley Railroad, between Harrisburg and Chambersburg, 51 miles, which road was opened in 1836-'37. One of them, the *Nicholas Biddle*, continued running until within a very few years. I think it ran thirty-eight years. It had only two drivers, about five feet diameter.

After the Pennsylvania Railroad Company had built their road over the Allegheny Mountain, only two miles north (at the summit) of the old Allegheny Portage Railroad, already described, with a ninety-five feet per mile grade between Altoona and the summit, near Gallitzin, and when the Portage Road, with its ten inclined planes, had been in use about twenty years, the Legislature of Pennsylvania directed surveys to be made to ascertain the feasibility of a graded railroad between Hollidaysburg and Johnstown. Robert Faries, C. E., who was then in the service of the State, made that survey, and reported it to the State authorities; whereupon the Legislature appointed, by name, Edward F. Gay, C. E., Robert Faries, C. E., and myself, a commission to examine, not only that route, but also the old Portage Railroad, and to report upon the advisability of retaining all or some of the inclined planes, or, of adopting a graded line, avoiding all the inclined planes. After examining, we were unanimously of opinion that it was better to abandon all the inclined planes and adopt the general line which had been surveyed by Mr. Faries, having a maximum gradient, on the eastern side, of seventy-five feet per mile, and on the western side of fifty-two and eight-tenths feet per mile; and, at the request of the other members, I wrote the report at Altoona, upon which the Legislature ordered the immediate construction of the graded road, which was then at once constructed under the superintendence of Mr. Faries.

This new State railroad and the Pennsylvania Railroad crossed the summit of the mountain within about half a mile of each other; the latter being the furthest north, and both having summit tunnels on the eastern approaches, the Pennsylvania Railroad tunnel being 3,750 feet, and the State tunnel 1,850 feet long. The two roads are in sight of each other for several miles east of the summit, occupying opposite sides of a deep, roman tic gorge; while on the western slope of the mountain they were for miles laid side by side, both passing down the Valley of the Conemaugh, to Johnstown.* Few travelers who view the beautiful scenery

* At the time that the above Commission were engaged in examining the questions submitted to them, I received a letter from my friend J. Edgar Thomson, President of the Penn-

of this part of the Allegheny Mountains are aware that there are two important railroads, now dead, almost in sight.

Soon after the completion of the new graded railroad over the mountain, built by the State, and the abandonment, excepting at a few points, of the once famous "Allegheny Portage Railroad," the public works of Pennsylvania were sold, and the Pennsylvania Railroad Company became the owner of all the State railroads and canals between Philadelphia and Pittsburgh.

That company shortly after abandoned the use of the new State railroad, took up its excellent rails, and transferred them to the Pittsburgh, Fort Wayne and Chicago line; and thus ended the last vestige of State railroad operations in Pennsylvania. I therefore literally attended at the birth of Pennsylvania State railroads, assisted them in their youth as well as in their mature growth, and witnessed their final obsequies; all in a period of about twenty-five years.

In the fall of 1857, I was invited to visit Brazil to examine the "Dom Pedro Segunda Railway," for the purpose of offering proposals for its construction across the "Sierra," back of Rio Janeiro. I sailed in December of that year, and arrived there in January, 1858. In May, 1858, in company with five other gentlemen, all of the United States, I closed the contract, in the City of Rio Janeiro, with the "Dom Pedro Segunda Railway Company," for the construction of their road.

That road, at that time, was regarded as the most difficult and expensive railway of the period; though since then more difficult and more costly works have been projected and carried through in Europe, and some with even bolder features have been constructed on the Pacific coast of South America. The limit of grade and curvature adopted on the Dom Pedro Segunda Railroad was the same as had been used on the Pennsylvania Railroad in crossing the Allegheny Mountain above Altoona, namely, ninety-five feet per mile on tangents, and curves of eight degrees deflection per hundred feet. This limitation in the case of the Dom Pedro Segunda Railway, with the very rough topography of that

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sylvania Railroad Company, to the effect that that company was then entertaining serious thoughts of building an *inclined plane* railroad over the mountain, *for their freight business;* under the impression that it would be cheaper to transport freight that way than by their graded road. It is of course a question for discussion. Our calculations at the time, however, showed that the State could transport cheaper on the graded road having a maximum grade of 75 feet per mile than it could on the road with inclined planes. At that period the State and the railroad company stood in the attitude of *rivals* for the great trade of the West passing over the Allegheny Mountain. There is, or should be, a history of the sale of the public works of the State; but it does not properly belong here.

region, involved a large amount of very heavy work, deep granite rock cutting and very high fills. There were thirteen tunnels in the space of nine miles of the mountain division, one of which, at the summit, was seven thousand two hundred feet long; another nearly half a mile, the residue shorter; making together three and a half miles of tunnel in nine miles of line.

About the year 1863–64, the road being well advanced on the eastern or ocean side of the mountain, and considerably forward on the western or Parahyba Valley side, it became obvious that time and money might be saved to all parties by the construction and use of a temporary track around the *Tunel Grande*, or "Big Tunnel," as we Americans called it; and the railway company consented to allow the sum of about $125,000 toward building such temporary road. It was accordingly constructed, with maximum grades of about 238 feet per mile, with curves of only 230 feet radii. The summit of the mountain which had to be surmounted was about 500 feet above the grade of the railway at the eastern portal of the Big Tunnel. The length of the temporary track was about five miles, three of which were on the eastern, and two on the western side. This track was used more than two years, during which a large amount of material, including the iron rails for the western side of the main line, was carried over; and much freight, especially coffee, and many passengers were daily transported upon it; and no accident ever occurred.

The locomotives were built by Baldwin & Co., of Philadelphia. They were Moguls, and weighed 42 tons each. They turned the curves easily, and usually took over a baggage car, an eight-wheeled American passenger car, and four or five large four-wheeled freight cars. They were limited to a slow rate of running, about five to six miles an hour; though they could have run somewhat faster, had it been desirable; but absolute safety was deemed an essential element in the management of a great and novel work among a people who were yet unaccustomed to railroads; many of whom persisted in declaring that they "would *never ride under the Sierra* through the Big Tunnel!"

It may as well be stated that although a chartered company intervened between the contractors who were building the railway and the Government of Brazil, the government itself was the real party. The government guaranty of seven per cent. per annum interest, made the stock worth several per cent. above the par of gold in the British market, and it was well understood that on the completion of the railway the government would take possession and run it, which it did.

The Emperor, "*Dom Pedro Segunda*," whose name the railway bears, was not one of that class who entertained any apprehension about riding through the Big Tunnel; although at that period he had not visited Europe.

[Recently the people of the United States and of the principal countries of Europe have had opportunities of seeing what manner of man the Emperor of Brazil is—intelligent and studious, yet full of energy and life, quick to perceive, and remarkably ready in the comprehension of all improvements calculated to elevate the standing of the Brazilian Empire.]

During the progress of the railway works the Emperor visited the line several times in person, riding, wherever it was practicable, on horseback or muleback, and walking where it was otherwise, in tunnels, etc., and critically inspecting every part, and asking very practical questions. Without the slightest hesitation he descended, in the ordinary cage, the wet shafts of the *Tunel Grande*, 340 feet in depth. When the time came for blowing away the last remaining barrier of rock—only three or four feet thickness of granite to open a continuous passage through the main tunnel, the Emperor was there; he walked up to the solid face, listened to the sound of a hammer on the other side, saw the drill-holes, which were loaded and partly loaded, and then, stepping back a few hundred feet behind a safety barricade, awaited the firing, which a few minutes later took place; and the Emperor was the first man to pass through the space which the blasting had made; the writer following closely, accompanied him through to the other side, where we met and were assisted over the débris by Mr. Boyd, the manager of the western portion of the tunnel; the whole party then walked through the temporarily illuminated tunnel to the western portal. This was not so grand a display as that which took place a year or more later, when the imperial train of cars inaugurated the final complete opening; but it served to show most strikingly the very practical character of the Emperor.

The temporary track over the mountain was used for a considerable time after daylight first shone through the tunnel; for very much still remained to be accomplished inside. Strange as it may seem, this granite mountain, where it was highest, about five hundred feet above the tunnel grade, instead of being very solid, as it had been anticipated it would be in the line of the tunnel, consisted of very wet, partly decom-

posed granite, subject to heavy caving and sliding, and requiring a large amount of stone arching and side walls. This delayed the completion and augmented the cost. The entire construction, including the sinking of the four working shafts, occupied about seven years. The credit of the admirable management of this difficult tunnel work belongs chiefly to Jacob Humbird, now of Cumberland, Maryland. Mr. Humbird's earliest tunnel experience, when he was a very young man, was in connection with the first regular railroad tunnel in the United States, already referred to, in 1831, on the Allegheny Portage Railroad, as a foreman.* Afterward he had large experience upon tunnels on the Baltimore and Ohio Railroad, under Mr. B. H. Latrobe, C. E.

On the Baltimore and Ohio Railroad, upon which Mr. Latrobe was so long its distinguished chief engineer, the experience in the use of heavy inclines on temporary tracks was much more complete than any with which I had personal connection, or than has occurred anywhere else, so far as I know, where freight and passengers have been regularly conveyed by locomotives. Until it was mentioned by a member at the last meeting I was not aware that a portion of the grade on the temporary track at Kingwood Tunnel, on the Baltimore and Ohio Railroad, was so great as 10 feet per hundred, or 528 feet per mile. I had been under the impression that the heaviest grade on the Baltimore and Ohio Road, where steam had been used, was at *Parr's Ridge*, only about 360 feet per mile.

I have since seen a printed copy of Mr. Latrobe's admirable paper on the subject—which he kindly sent me, and which was published in the *Railroad Gazette* of December 5th, 1874, which gives, in the clearest manner, all the particulars, with maps and profiles of the main line, both at "Kingwood" and "Board Tree Tunnel."

I may be permitted to quote a few points. In regard to "Parr's Ridge," Mr. Latrobe wrote, referring to Kingwood and Board Tree Tunnel grades:

"The occasions referred to were not indeed the first upon which loco-
" motives had ascended steep inclines, for one of the little 8-ton grass-
" hopper engines of the Baltimore and Ohio Railroad has mounted and
" descended the original grades of that road across Parr's Ridge (one of

* That tunnel was constructed under the immediate charge of Mr. S. W. Roberts, C. E., as principal assistant under Mr. Sylvester Welch, C. E., the Chief Engineer. It was 901 feet long and had a double track through it. It was 25 feet wide.

"which was 360 feet per mile, since superseded by one of 82 feet). An "engine of some 10 tons, built by the late William Norris, had also "ascended the old Schuylkill inclined plane near Philadelphia, and no "doubt those experiments upon a small scale encouraged those upon a "more extended one of which I have given the preceding account."

The letter of Mr. Latrobe, just mentioned, is the most interesting, complete and satisfactory presentation of experience on steep inclines used by locomotives that I have ever seen. It should be read by every member of our Society who feels interested in this particular subject.

"At Kingwood Tunnel, on the Baltimore and Ohio Railroad, the top of the ridge was 210 feet above level grade of road at east end of tunnel. Temporary track on the east side reached summit in 3,400 feet. Grade first 2,200 feet, not uniform—steeper at first, then more moderate, till 90 feet height attained; average, 216 feet per mile. Remaining 1,200 *feet distance* and 120 *feet height*, 528 feet per mile, completed in a curve of 180 degrees, with a radius of 300 feet and 400 feet."

A grade of 1 in 10 on a curve of only 300 feet radius requires greater power to overcome gravity and friction than one of 10¼ feet per 100 of straight track.

The average ascent of the whole 3,400 feet, on the east side, was at the rate of 336 feet per mile, but the test of the power of the locomotive was on the "1,200 feet length of 1 in 10 grade, on a radius of 300 and 400 feet."

Look at the work performed:

An engine of 28 tons (56,000 lbs.), tender 34,000 lbs., car of iron and other materials at 30,000 lbs.; total 120,000 lbs., or 60 tons of 2,000 lbs. taken up a grade of 528 feet per mile, through a curve of 300 feet radius. "The grade and curvature on the west slope were much lighter than on the east slope; falling 305 feet in 7,000 feet; averaging 1 in 23, or about 230 feet per mile."

Mr. Latrobe states that the steep grade was used about two months in 1852; and that afterward an improved temporary line track reduced the grade from 528 to 230 feet per mile.

At "*Board Tree Tunnel*," Mr. Latrobe describes another "temporary track, having a grade of 1 in 20, or 264 feet per mile, overcoming 328 feet; with two switch backs on the east and five on the west side. Maximum grade 6 feet per 100, or 316⅘ feet per mile, other reaches 4 feet per 100, or 211 feet per mile. Engine 56,000 lbs., tender 34,000

lbs., *two* loaded cars 30,000 lbs. each; total 150,000 lbs., or 75 net tons. When pressed, another car could be added, and still another."

Mr. Latrobe, in his able paper, refers also to a pamphlet published by the late Charles Ellet, C. E., in 1856, entitled "MOUNTAIN TOP TRACKS."

Since this paper was read before the Society the profession of civil engineers has been called to mourn the death of Mr. Latrobe.

Mr. Latrobe, very shortly before his last illness, mentioned to the writer that he had promised to prepare an article embodying some of his early engineering experiences, to be published in the "Railroad Gazette." His death has therefore deprived the profession of "experiences" which would doubtless have been interesting and valuable.

There are some of our older engineers yet living, who might confer benefit by gathering together and publishing for preservation and future reference the engineering experience of their early days. In the course of events but a few years can elapse ere all the engineering pioneers of our country will have departed.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INSTITUTED 1852.

TRANSACTIONS.

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Vol. VII.—August, 1878.

DISCUSSION

ON INCLINED PLANES FOR RAILROADS.

By O. CHANUTE and WILLIAM H. PAINE.

Mr. O. CHANUTE: The valuable paper contributed by Mr. Wells, and the very interesting reminiscences of early American achievements in railroad operating which it has called forth from the members of the Society seem to me to fully confirm the conclusion already reached by railway managers the world over, that the frictional adhesion of locomotive driving wheels upon the rail is sufficient to work almost any gradient likely to be found necessary in practice, and is upon the whole much the most economical to adopt.

Other methods of traction, such as pneumatic tubes, ropes, griping wheels upon a central rail, and racks and cog wheels have gradually been given up, as ineffectual and uneconomical complications; except perhaps for gradients of 15 or 20 feet per hundred, as at Mount Washington and at the Righi, where the latter method is in use. We find that at Madison,* upon a grade of 6 feet per hundred, frictional traction has superseded the rack and cog wheel, and I believe that in all cases where the topography of the country compels the use of gradients of say 4 or 5 feet per hundred, the weight of the boiler and working parts, necessary to generate and apply the power required, will be found sufficient to give the necessary adhesion to utilize that power.

* See Transactions, Vol. VII, page 64.—(March, 1878.)

This, in a measure, results from the improvements which modern practice has introduced in locomotives. These consist mainly in a better distribution of the weights upon the driving wheels, and in America, especially, in equalizing them by levers connecting the drivers with each other, so as to keep the relative weights upon them constant, while allowing them to adjust themselves to the inequalities of the track.

These equalizing levers, together with the centre-bearing truck under the front end of the engine, constitute the leading features of the American locomotive, which is undoubtedly more effective for a given weight than the type still adhered to by the Europeans.

In the early days of railroads it was assumed that an adhesion of $\frac{1}{4}$ or $\frac{1}{5}$ of the weight upon the driving wheels was a satisfactory performance. In France and in England, at the present day, the ordinary practice is to estimate for an adhesion of $\frac{1}{6}$ or $\frac{1}{7}$, while our locomotives work up regularly to $\frac{1}{5}$ in summer and $\frac{1}{4.5}$ in winter, of the weight on the drivers, with occasional performances much in excess.

The account given of the trial trip at Madison is a good case in point.

Upon the 9th of April, 1875, the engine took 210 tons (including its own weight), up a grade of $\frac{1}{16.5}$ or 6.06 feet per hundred, on a straight line, at a speed of 6 miles per hour. The resistance may, therefore, be estimated as follows:

Gravity, $\frac{6.06 \times 2000}{100}$	=	121.20	pounds per ton.
Wheel friction generally	=	6.	" " "
Atmospheric resistance, say	=	1.80	" " "
Total resistance,		129.	" " "

Traction = 210 tons × 129 pounds = 27090 pounds.

As the engine weighed 112 000 pounds or 56 net tons.

Adhesion, $= \frac{27090}{112000} = \frac{1}{4.13}$ or nearly one quarter.

Recent performances on the Boston and Albany Railroad gave an adhesion, if I remember rightly, of $\frac{1}{3.6}$, while on the 3d of July, 1877, the "*Mogul*" locomotive "*Oakland*," started from a stand still "on a grade "of 83 feet per mile, combined with a 2-degree curve, 45 empty eight-"wheeled cars, weighing 669,500 pounds, or 334.75 net tons, and with-"out slipping her drivers took the train up and beyond the gradient, "something more than half a mile, gaining speed and steam as she

"went," as reported by Mr. J. M. Goodwin, Engineer of the Sharpsville and Oakland Railroad, in a letter recently printed by the builders of the locomotive.

As the gradient is one of 1.58 feet per 100, the resistance is estimated as follows :

$$\text{Gravity } \frac{1.58 \times 2000}{100} = 31.60 \text{ pounds per ton.}$$

2 degree curve at ½ pound per °,	1.00	"	"	"
Wheel friction,	6.00	"	"	"
Atmospheric resistance, say,	1.40	"	"	"
Total resistance,	40.00	"	"	"

Traction—Train.. 334.75 tons.
Engine, 33.50 "
Tender, 15.00 "

Total, 383.25 tons × 40 pounds = 15,320 pounds.

Adhesion.....15,320 lbs. / Weight on drivers..57,000 lbs. $= \frac{1}{3.72}$ ratio of adhesion.

A performance by no means to be regarded as singular, as the new "consolidation" engines upon the Erie Railway work regularly up to a maximum traction of 19,500 pounds, as measured by the dynamometer and have occasionally indicated 22,000 and 24,000 pounds, with a weight upon their eight driving wheels of 87,500 pounds.

$$\text{In this case the adhesion is } \frac{19{,}500}{87{,}500} = \frac{1}{4.49}$$

The usual method of computing train resistances being to allow 10 or 10½ pounds per ton, while I have above stated the wheel friction at only 6 pounds per ton, it may be well to explain how it is arrived at.

In 1854 the late Mr. Zerah Colburn made a number of careful experiments on the Erie Railway, from which he deduced the conclusions that the resistance from wheel friction upon a straight line was 4½ pounds per ton, and on curves ½ pound per degree in addition.

The train which he experimented with, however, was specially prepared for the occasion, and more perfect in lubrication and fitting of journal bearings than those met with in ordinary practice. We find, by recent experiments with a dynamometer upon the Erie Railway, that the wheel friction of ordinary trains on a straight line is generally 5¼ pounds per ton, but we call it 6 pounds to be safe. We find also that

the additional curve resistance is as near as may be ½ pound per ton per degree, as stated by Mr. Colburn.

The atmospheric resistance varies, of course, with the square of the speed, or nearly so, as it is mainly composed of the end pressure, varying as the square of the speed, and the friction of the air upon the sides of the train, which, in consequence of the gaps between the ends of the cars it is difficult to estimate accurately. We found that with two empty freight cars, at 30 miles an hour, the atmospheric resistance was 700 pounds, and with 20 empty cars at the same speed it was 900 pounds. In the first instance it was, therefore, 35 pounds per ton, and 4½ pounds per ton in the second. But if the cars had been loaded it would have been no more in the aggregate, and expressed in terms of the tonnage, would have been 17½ and 2¼ pounds per ton respectively.

As the end surface of a freight car is about 100 square feet, and the air pressure due to a speed of 30 miles an hour is 4.43 pounds per square foot, it will thus be seen that the atmospheric end resistance was 443 pounds, while the remaining 257 pounds in the first case, and 457 pounds in the latter case were due to the friction against the sides and the pressure against the partly uncovered ends of the cars succeeding that on the front end of the trains. For ordinary loaded trains, consisting of 25 to 40 loaded cars, we usually allow from 2 pounds to 1.20 pounds per ton for atmospheric resistance, at speeds varying from 15 to 25 miles per hour.

To the question asked by one of the members present, as to what gradient is required to work a railroad by gravity, I would answer, that if the wheel friction is correctly stated at 6 pounds per ton, the equivalent angle of repose would be 0.30 per 100 feet, or 16 feet per mile on a straight line. The curves adding a resistance of a half pound per degree, would, if ruling at 4 degrees, or 1 432 feet radius, add 2 pounds per ton to that on a straight line, or 0.10 per 100 feet, thus making the angle of repose $\frac{(6+2)\,100}{2\,000} = 0.40 = 21.12$ feet per mile, while, when we take into account the atmospheric resistance at 25 or 30 miles per hour, and the expediency of having a surplus power (to be controlled by brakes), in order to start the cars promptly, and to get the trains out of the way of those following them, we find that in practice we need gradients of about 40 feet per mile to work trains by gravity, which corresponds to a resistance of 15.2 pounds per ton, or 0.76 per 100 feet.

MR. WILLIAM H. PAINE,—I have visited a number of inclined planes within the past few years, for the purpose of investigating the subject of wire rope traction.

The most extensive and best appointed of those which I have seen operated in this manner are located on the Central Railroad of New Jersey, at Solomon's Gap, near Wilkesbarre, Pa.

There, by three inclines, a height of more than 1 000 feet is attained in less than 3 miles thereby avoiding a detour on the main line of 13 miles. This short cut is devoted to coal traffic.

The principal characteristics of these planes are as follows :

PLANE.	LENGTH.	RISE.	RISE.	FALL.	LOAD.
	Feet.	Per cent.	Feet.	Feet.	Tons.
No. 1	3 700	9.28	334.7		144
Level	600			5.40	
No. 2	3 000	14.65	422.2		99
Level	720			6.75	
No. 3	5 000	5.70	269.		198
Total	13 020		1 025.9	12.15	

Incline No. 1 was operated with an iron wire rope 2¼" diameter. One rope had hauled 7 000 000 tons before it was laid aside. The average speed was 6 miles per hour..

The method here employed, as on most other such planes, was the alternating system. After the train was hauled up, the cars were run back by reversing the engine. A dummy, or pusher, was permanently attached to the rope, which pushed the cars before it in ascending.

The advantages of a circulating system over this method seemed very apparent, as then the rope would run continuously in one direction, the loaded cars ascending on one track and the empty cars descending on another.

The one thing required to make such a plan practicable was a suitable attachment by which the cars could be secured to the rope in such a manner as to allow them to start slowly and gradually acquire the full speed of the rope.

This I have been able to accomplish by the following device. (See

FIG. 1.

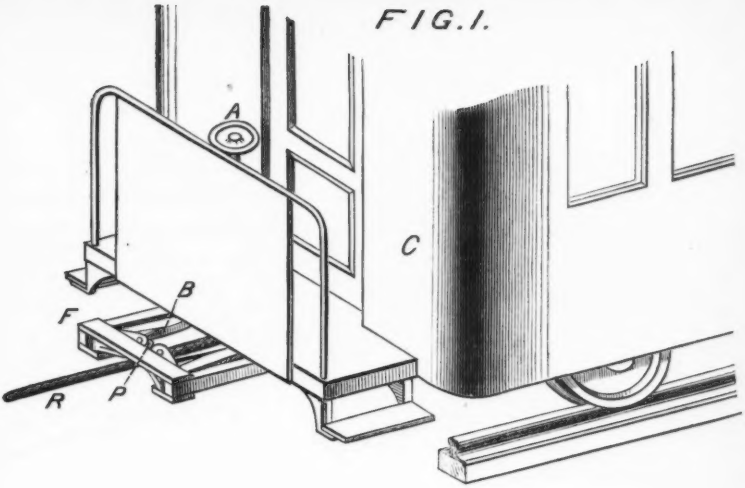


FIG. 2.

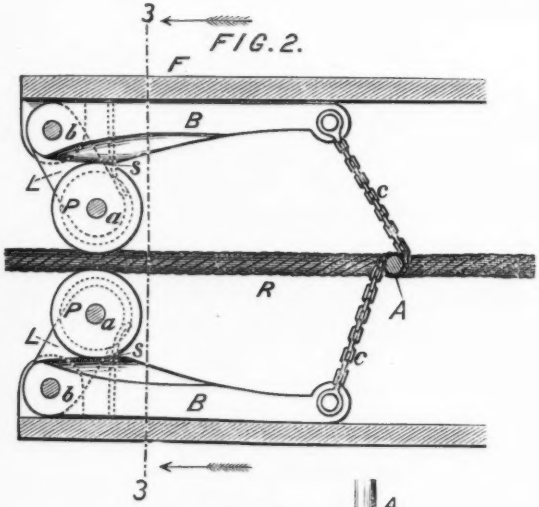


FIG. 3.

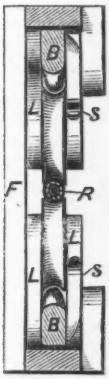
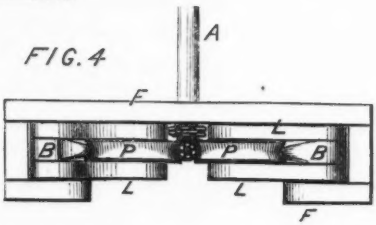


FIG. 4



cut.) In a frame attached under the front end of a car are one or more pairs of grooved rollers, so placed as to embrace the moving rope between their grooved faces. Brakes are applied to these rollers so as to press them against the rope more tightly and at the same time retard their motion. This causes the car to start, and its speed to be accelerated in proportion to the amount that the rollers are retarded in their revolutions. When the revolutions of the rollers are wholly stopped the car will have acquired the full speed of the rope.

REFERENCES.

R.—The moving rope.

PP.—The grooved rollers.

LL.—Links carrying the rollers and pivoted on the frame at their other ends.

BB.—Brakes operating against the rollers.

A.—Rod or capstan on which the chains are wound which move the brakes.

When the car is stationary, and the brakes free, the rollers will be revolved by the moving rope; but by applying the brakes, so as to retard the motion of the rollers, the car will move forward at any desired speed up to that of the rope.

This system has been adopted on the Sutter Street Railroad in San Francisco, where it has been in successful operation for more than a year.

The Superintendent writes that nothing better could be devised. It will take a heavy load up the steepest grades on the road, and run at any speed desired equal to or less than the speed of the cable without wearing the rope or cutting the rollers.

I have collated the characteristics of this road, and also of the Clay Street Road, which latter is run by brakes, engaging the rope directly without intervening sheaves.

A peculiarity of both of these roads is the fact of running the rope under ground in a large tube having a narrow slit along the top, through which passes the stem which carries the attachments.

Sutter street inclines are 5,315 feet long; steepest grade, 7.27 feet per hundred.

Clay street, length 3,389 feet; steepest grade, 16 feet per hundred.

I find a description with plates of both these roads in *Annales des*

Ponts et Chausses for November last. Photographs are also at the rooms of the American Society of Civil Engineers.

This method of attaching cars to moving ropes seems capable of a wider application than simply upon inclined planes, as there are many other places where it would be desirable to dispense with the locomotive, if possible, as on elevated railroads, on bridges, and in tunnels.

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CLXVII.

(Vol. VII.—August, 1878.)

DISTRIBUTION OF RAIN-FALL DURING THE GREAT STORM OF OCTOBER 3 AND 4, 1869.

By JAMES B. FRANCIS, C. E., Member of the Society.

Read at the Tenth Annual Convention, June 18th, 1878.

In the construction of catch-water reservoirs, mill dams, culverts in railway and other embankments, and many other works, provision has to be made for the maximum flow of water. In small areas this depends, to a great extent, on the maximum rain-fall in a given time.

The proportion of the rain-fall that flows off during a given time varies very much, depending on the extent and character of the water-shed and other circumstances. In each case the various considerations

affecting it have to be taken into account in deciding on the flow that should be provided for.

In small areas the fundamental datum is, however, the amount of rain-fall to which the locality is liable in a given time, leaving the proportion of the same that ought to be provided for, to be determined by experience or the judgment of the engineer.

As a contribution to the knowledge on this subject, I submit to the Society some facts and deductions from the same, relating to a great rain that occurred in the eastern part of the United States in October, 1869.

The newspapers of the time contained accounts of the great floods that resulted from this rain in various parts of the country, and put it beyond question that in some localities it was very extraordinary. Being at the time much interested in the subject, I addressed a circular to the meteorological observers for the Smithsonian Institution, in the Eastern States, and other persons and institutions likely to have observed the amount of rain-fall.

The following table has been compiled principally from the replies to this circular.

To ascertain approximately the areas on which certain amounts of rain fell, I have prepared a map of a large part of the region in which the rain-fall at certain points was ascertained.

This map has been compiled, mainly, from maps recently issued by the United States Post Office Department. Several of these maps are on a scale of six miles to the inch. These have been put together, and the map has been completed by reducing those on a different scale to the same scale of six miles to the inch.

In this manner I have obtained a map on an unusually large scale, embracing nearly the whole of the New England States and parts of New York, New Jersey and Pennsylvania, and from the data contained in the following table, I have projected on it isohyetal lines, or lines of equal rain-fall, representing the rain-fall during this storm. A reduced copy of part of this map accompanies this paper.

TABLE I.

Amount of Rain collected in Rain Gauges at the several stations named, during the great storm which ended in Massachusetts on Monday, October 4, 1869.

STATIONS, &c.	Observer or informant.	TIME.		Depth of Rain in inches.	REMARKS.
		Commenced Raining.	Stopped Raining.		
DOMINION OF CANADA.					
Quebec	Rev. Father Anthony	Oct. 3	Oct. 5	0.91	
Montreal	Louis Lesage	" 2	" 4	2.05	
Halifax	G. Murdock			1.58	
St. John	Do.	Oct. 4, 6 P. M	Oct. 5, A. M.	0.53	
MAINE.					
Houlton	C. H. Fernald	Oct 3, 10 A. M.	Oct. 5, 5 P. M.	3.61	
Steuben	J. D. Parker	" 4, 9 "	" 4, 8 "	0.60	
Williamsburg	E. Pitman		" 4,	5.30	
Orono	M. C. Fernald	Oct. 3, 2:30 P. M.	" 5, 1:30 P. M.	2.13	
West Waterville	B. F. Wilbur	" 3, 6 A. M.	" 4, 6:40 "	4.10	
Gardiner	R. H. Gardiner			3.37	
Lisbon	A. P. Moore			2.70	
Rumford	W. Pettingill			8.00	
Norway	H. D. Smith	Oct. 3, 6 A. M.		6.70	2.50 inches of rain fell in two hours, Oct. 4, P. M.
Standish	J. P. Moulton			4.31	
Fort Preble, Portland	Dr. E. Cowles	Oct. 3, 5:30 A. M.	Oct. 4, 6 P. M.	1.99	
Cornish	Siles West	" 3, 4 "	" 4, 5 "	6.43	
Do.	G. W. Guptill	" 3	" 4	6.15	

New Hampshire.					
Dover	Asa A. Tufts				3.20
North Barnstead	Charles H. Pitman			Oct. 4	7.40
Weir's Landing	Josiah B. French				6.40
Lake Village	Do.				6.77
Goffstown	Alfred Colby			Oct. 4, P. M.	8.06
Concord	W. L. Forster	Oct. 2, 12 P. M.		" 4, "	7.40
Hanover	Shattuck Observatory	" 3, A. M.		" 4, 5 P. M.	5.88
Vermont.					
Lunenburgh	H. A. Cutting				4.00
North Craftsbury	Rev. E. P. Wild	Oct. 3		Oct. 5	4.49
Randolph	C. S. Paine			" 4	5.28
Burlington	University of Vermont	Oct. 3		" 5, A. M.	3.71
West Charlotte	Miss M. E. Wing			" 5, 9.15 A. M.	5.00
Panton	D. C. Barto				4.25
Middlebury	H. A. Sheldon	Oct. 3, 6 A. M.		Oct. 5, 11 A. M.	3.98
Castleton	Rev. R. G. Williams	" 3, 4 "		" 5, 1 P. M.	6.57
Woodstock	H. Doton	" 3, 6 "		" 4, 5 "	6.35
Massachusetts.					
Kingston	G. S. Newcomb			Oct. 4	1.75
New Bedford	Samuel Rodman	Oct. 3, 8 P. M.		" 4, 4:30 P. M.	1.50
Milton	Rev. A. K. Teele				1.15
West Roxbury	Thomas Motley				1.46
Jamaica Plain	J. J. Dixwell	Oct. 3		Oct. 4	1.45
Fort Warren	Dr. J. H. Kinsman				0.90
Boston	W. H. Bradley	Oct. 3		Oct. 4	1.76
Do.	Robt. Treat Paine	" 3		" 4	1.52
Topsfield	S. A. Merriam			" 4	1.77
Georgetown	S. A. Nelson	Oct. 3, 0:10 P. M.		" 4, 6 P. M.	2.25
Lawrence	John Fallon	" 3, 12 M.		" 4, 4:30 P. M.	3.56
Cambridge	Harvard College Obser.	" 3,		" 4	1.58
Waltham	S. R. Scott				1.65

{ 4.27 inches of rain fell between 11 A. M. and 2 P. M. Oct. 4.

{ 4.00 inches of rain fell between 0:30 P. M., and 2:30 P. M., Oct. 4.

TABLE I.—*Continued.*

STATIONS, &c.	Observer or Informant.	TIME.		Depth of Rain in inches.	REMARKS.
		Commenced Raining.	Stopped Raining.		
West Newton	J. H. Bixby			2.23	
Lake Cochituate	A. Stanwood			4.00	
Lowell	Merrimac M'f'g Co.			3.42	
Do.	Prop's locks and canals			2.84	
Lunenburg	G. A. Cunningham	Oct. 3	Oct. 4.	7.60	
Fitchburg	Dr Jabez Fisher	" 3	" 4	7.53	About 3 inches of rain fell between 11:30 A. M. and 2 P. M., Oct. 4.
Worcester	Dr. Joseph Draper		" 4	4.75+	Rain gauge overflowed.
Amherst College	Prof. E. S. Snell	Oct. 3	" 4	5.83+	Do. do.
Chicopee	C. H. Nye			8.71	
Springfield	L. C. Allen, U. S. Army	Oct. 3, 2 A. M.	Oct. 4, 3:15 P. M.	8.05	
Do.	J. Weatherhead		" 4	7.50	
Hinsdale	Rev. E. Dewhurst	Oct. 3		6.80	
Pittsfield	Thos. Colt		Oct. 4	6.00	
Williams College	Prof. A. Hopkins			6.00	
Richmond	Wm. Bacon	Oct. 3, 3 P. M.	Oct. 4, 3 P. M.	3.97	More than one half the quantity fell between 8 A. M. and 11 A. M. Oct. 4.
RHODE ISLAND.					
Fort Adams		Oct. 3, 8:40 P. M.	Oct. 4, 10:30 A. M.	0.90	
Providence	Dr. Caswell			0.83	
CONNECTICUT.					
Hartford	Prof. Pynchon			8.43	At Water Works Reservoir.
Do.	C. J. Hoadly		Oct. 4, 3 P. M.	8.11	Rain gauge supposed to have overflowed.

Canton	Geo. I. Case			12.35	
New Haven	Prof. Loomis			4.30+	Rain gauge overflowed.
Do.	Dr. Munson			6.00+	Do. do.
Middletown	Prof. Johnston	Oct. 3.	Oct. 4	8.90	The whole amount fell in a little more than 30 hours.
Do.	H. D. A. Ward	" 3.	" 4.	9.37	7.15 inches of rain fell between 2 P.M. Oct. 3, and 2 P.M. Oct. 4, the whole quantity in 37 hours.
Colebrook	Miss C. Rockwell	Oct. 3, 3 A.M.	Oct. 4, 9 P.M.	8.44	
Brookfield	Rev. S. W. Roe			5.50	
NEW YORK.					
Moriches	E. A. Smith	Oct. 3. 8:50 A.M.	Oct. 4, 1:30 P.M.	5.34	
Fort at Willet's Point	Gen. H. L. Abbot	" 3, 12 P.M.	" 4, 1 P.M.	7.85	
Flatbush	Rev. E. T. Mack	" 2, 9:30 P.M.	" 4, P.M.	3.46	
Fort Schuyler	Gen. H. L. Abbot			8.00	
City Hall Park	Croton Aq. Dept.	" 3, 11 P.M.	Oct. 4, 12 M.	4.11	
Central Park	Central Park Com.			3.92	
New Reservoir, 86th st.	Croton Aq. Dept.		Oct. 4.	4.09	
High Bridge	" "		" 4.	4.50	
Tarrytown	" "		" 4.	4.45	
Croton Dam	" "		" 4.	5.10	
Kent	" "		" 4.	5.22	
Ardenia	T. B Arden			4.63	
West Point	J. Muller, Hos. Stw'd		Oct. 4, 11.30 A.M.	5.25	
Newburgh	Jas. H. Gardiner			5.30	
Middlehope	Leander Clark			4.77	
Glasco	D. B. Hendricks			4.75	
Hudson	Dr. G. P. Hackenberg			7.90	
Albany	Prof. Ten Eyck	Oct. 3.	Oct. 5.	6.01	
"	Dudley Observatory	" 3, 5:30 P.M.	" 4, 12 M.	5.86	
Troy	Water Commissioners.	" 3.	" 5.	5.46	
South Hartford	G. M. Ingalsbe	" 3, 1 P.M.	" 5, 3 P.M.	5.89	
Plattsburgh Barracks	Maj.-Gen. Arnold	" 3, 1 A.M.	" 5, 8 P.M.	3.01	
Minaville	J. W. Bussing	" 3.	" 4, 9:30 A.M.	5.25	

TABLE I.—*Continued.*

STATIONS, &c.	OBSERVER OR INFORMANT.	TIME.		DEPTH OF RAIN IN INCHES.	REMARKS.
		Commenced Raining	Stopped Raining.		
South Trenton	Storrs Barrows	Oct. 1	Oct. 4	2.28	
Leyden	C. C. Merriam	" 2	" 4, P. M.	3.60	
Houseville	Walter D. Yale	" 3	" 5, 8 A. M.	2.02	
Gouverneur	C. H. Russell	" 2	" 5, A. M.	2.87	
North Hammond	C. A. Wooster	" 2, 6:20 P. M.	" 5, A. M.	3.35	
Oneida	Dr. S. Spooner	" 3	" 4	5.84	
Palermo	E. B. Bartlett		" 5, A. M	2.70	
Oswego	W. S. Malcolm			2.15	
Depauville	Henry Hass	Oct. 4, 6 A. M.	Oct. 4, 3 P. M.	2.60	
Newark Valley	Rev. S. Johnson	" 2, 5 P. M	" 5	2.80	
NEW JERSEY.					
Paterson	Wm. Brooks	Oct. 3	Oct. 4	4.15	
Newark	W. A. Whitehead	" 3, 0 A. M.	" 4, 12 M	3.33	
Newton	Dr. T. Ryerson	" 3, 3 A. M.	" 5, 8:30 A. M.	7.11	5.21 inches of rain fell between Oct. 3, 4:30 P. M., and Oct. 4, 9 A. M.
New Germantown	Arthur B. Noll	" 3, 5 A. M.	" 3, 8.30 P. M.	4.43	
Trenton	E. R. Cook		" 4	2.61	
Haddonfield	John Boadle		" 4	3.32	
Vineland	Dr. J. Ingram	Oct. 3, 5 A. M.	" 4, 10 A. M.	2.87	
Greenwich	Rebecca C. Sheppard	" 3	" 4	3.25	
Rio Grande	Mrs. J. R. Palmer		" 4	3.50	
Moorestown	Thos. J. Beans	Oct. 3, 9 A. M.	" 4, 8 A. M.	2.41	
PENNSYLVANIA.					
Nyces	John Grathwohl	Oct. 3, 4 A. M	Oct. 4, 8 A. M	7.50	
Hamlinton	J. D. Stocker	" 1	" 3, 6 A. M.	6.00	

Dyberry	Theodore Day	" 3	" 4, 9 "	4.15	3 inches of rain fell during the night of Oct. 3.
Fallsington	E. Hance	" 3, 8 A. M.	" 4, 11 "	2.90	
Horsham	Miss Anna Spencer		" 4	4.00+	Rain Guage overflowed.
Plymouth Meeting	M. H. Corson	Oct. 3, 6 A. M.	" 4, 10:30 A. M.	6.00	
Penn. Hospital	Dr. Conrad	" 3	" 4, 10:30 "	3.85	
Cor. 7th & Thompson Sts.	Jacob M. Ellis	" 2 P. M	" 4, 9 A. M	4.25	
Western part of Phila	Do.			3.75	
Germantown	Do.			5.20	
Westchester	Dr. Geo. Martin			3.76	Rain Gauge filled to within $\frac{3}{4}$ inch of top; probably a portion lost by splashing over.
Do.	Dr. Jesse C. Green			5.80	
Parkerville	Dr. F. Darlington	Oct. 3, A. M.	Oct. 4, 10 A. M.	5.24	
Phœnixville	Dr. J. L. Coffman			7.10	
Reading	J. Heyl Raser	Oct. 3, 3:15 A. M.	Oct. 4, A. M.	6.73	
Ephrata	W. H. Spera	" 2, 11:35 "	" 4, 4 A. M.	8.05	
Mount Joy	Dr. J. R. Hoffer			....	Rain Gauge out of order. Rainfall stated to be between 8 and 9 inches.
Factoryville	Rodman Sisson	Oct. 3, 1 A. M.	Oct. 4	4.67	
Tioga	E. T. Bently	" 2, 10 P. M.		2.00	
Lewisburg	Prof. C. S. James			3.60	
Carlisle	Dr. W. H. Cook	Oct. 2, 1 P. M.	Oct. 4, 2 A. M	4.50	
Fountain Dale	S. C. Walker	" 2, 2:30 P. M.	" 4, 3 "	4.58	
Grampian Hills	Elisha Fenton	" 2, 10 P. M.		0.57	
Johnstown	David Peelor	" 2, 7 P. M	Oct. 3, 9 "	0.76	
Franklin	Rev. M. A. Talman	" 2, 3:30 P. M.	" 5, 3:30 P. M.	0.47	
Canonsburg	W. Smith	" 2	" 4	1.40	
DELAWARE.					
Milford	Mrs. A. C. Whittier			1.50	
MARYLAND.					
Woodlawn	J. O. McCormick	Oct. 2	Oct. 4, 5 A. M.	3.97	

TABLE I.—*Continued.*

STATIONS, &c.	OBSERVER OR INFORMANT.	TIME.		DEPTH OF RAIN IN INCHES.	REMARKS.
		Commenced Raining.	Stopped Raining.		
MARYLAND—(*Continued.*)					
Annapolis	W. R. Goodman	Oct. 2, 11:30 P. M.	Oct. 4, 6:20 A. M.	5.25	
Mt. St. Mary's	Prof. C. H. Jourdan		" 4	5.12	
DIST. OF COLUMBIA.					
Washington	Smithsonian Institution	Oct. 3, A. M.	Oct. 4, A. M.	6.55	
VIRGINIA.					
Johnsontown	C. R. Moore	Oct. 3, 6:30 P. M.	Oct. 4, A. M.	1.05	
Comorn	E. Tayloe	" 3, daybreak.	" 4, 7 P. M.	5.42	5.05 inches of rain fell October 3d, between daybreak and midnight.
Fortress Monroe	Artillery School, U. S. A.	Oct. 2	" 3	1.98	
Hampton	J. M. Sherman	" 2, 4 A. M	" 4, 5 A. M	3.30	
Zuni Station	R. Binford	" 2, 11 "	" 3, 2 A. M.	3.16	
Bacon's Castle	B. W. Jones	" 3, 8 "	" 4, A. M.	3.80	
Staunton	J. C. Covell		" 4	2.25	
Lexington	W. H. Ruffner	Oct. 2, A. M.	" 3, 4:30 P. M.	2.75	
Snowville	J. W. Stalmaker	" 2, 7 P. M.		1.20	

It is obvious that the observations collected in Table I are quite insufficient for an accurate determination of the isohyetal lines, and until meteorological observers are greatly multiplied, a rough approximation is all that can be attained in such an investigation.

In projecting the lines it is assumed that the amount of rain varies uniformly from one station to the next. In some cases the stations are very far apart. Fortunately for our purpose, however, where the rainfall was the greatest, the stations were not so distant from each other, and the results may consequently be taken as nearer approximations.

According to the observations, the fall of rain was greatest at Canton, in Connecticut, about fifteen miles northwesterly of Hartford, where the gauge indicated 12.35 inches.

Mr. George I. Case, the observer, said in reply to the circular: "I measured 12.35 inches, but I do not think it could possibly have been so much. I think there was an unaccountable mistake somewhere." He appears to have had no reason to question the accuracy of his measurement except the extraordinary amount, but as the observations at other points in the vicinity, although indicating much less rain, are consistent with it as a culminating point, I see no reason for discrediting his observation.

As will be seen by the preceding table of observations, the storm extended southerly to New Jersey, Pennsylvania, Maryland, Washington and Virginia. I have, however, not attempted to map its course systematically, except in the New England States, and a small part of the State of New York, in Dutchess, Columbia, and Albany Counties, and parts of adjoining counties.

Omitting the part of the State of New York and other States not systematically mapped, it appears from the isohyetal lines that the watershed on which six inches or more of rain fell, is embraced in a single closed curve, extending from Long Island Sound to the northeasterly part of Maine, a distance of about 384 miles, with an average width of about 63 miles.

The area on which seven inches or more of rain fell is embraced within two closed curves with an interval between them, near the middle of Massachusetts, of about 30 miles.

The area on which eight inches or more fell extends from Haddam, in Connecticut, to Becket, in Massachusetts, a distance of about 65 miles, with an average breadth of about 28 miles.

The area on which nine inches or more fell extends from Middletown, in Connecticut, to the neighborhood of Blandford, in Hampden County, Massachusetts, a distance of about 50 miles, with an average width of about 21 miles.

The area on which ten inches or more fell extends from Kensington, in Connecticut, to near Tolland, Massachusetts, a distance of about 34 miles, with an average width of about 15 miles.

The area on which eleven inches or more fell is entirely within the State of Connecticut, with Canton for its central point; the extreme length is about 20 miles, and average width about 9 miles.

Table II gives the areas of water-shed on which rain of not less than certain depths fell during October 3d and 4th, 1869, obtained by planimeter and checked by scale from the map described above, all being embraced within single closed curves, except for seven inches, as described above. It will be understood that the area given for any rain-fall includes the entire area within its bounding curve, and, according to the method adopted, the rain-fall on every part of the area equals or exceeds the amount stated.

For example, the area for a rain-fall of nine inches, or more, given in the table, is 1,046 square miles. This area includes the 519 square miles given for ten inches, or more, and that again includes the 179 square miles on which the rain-fall was eleven inches, or more.

Strictly speaking, it is assumed that the rain-fall at the isohyetal line forming the bounding curve is just the amount stated, and that it increases uniformly to the next included isohyetal line, where it is one inch greater.

TABLE II.

DEPTH OF RAIN.	AREA OF WATER-SHED.
6 inches or more	24,431 square miles.
7 " "	9,602 " "
8 " "	1,824 " "
9 " "	1,046 " "
10 " "	519 " "
11 " "	179 " "

In Table I the fall of rain during certain parts of the storm is given by some of the observers, indicating a great inequality at different times.

At Concord, New Hampshire, out of the whole rain-fall of 7.40 inches, four inches fell in two hours on the afternoon of the second day of the storm, and undoubtedly in many other localities there was a like downpour, and in some places even more.

This inequality in the rate has an important bearing on the effect of such a storm on small areas.

The long continued and heavy rain must have filled up the ground and usual storage reservoirs, and, being followed immediately by a fall of rain which of itself would make a flood, great part of the latter in a hilly country must have passed at once into the streams, and the flow in the smaller streams, for some period of time, must have been nearly that due to the rate at which the rain was falling on the water-shed supplying them. In the larger streams, supplied from correspondingly larger areas, the discharge is spread over a longer time, and the rate of flow would, of course, be proportionally less.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INSTITUTED 1852.

TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

CLXVIII.

(Vol. VII.—August, 1878.)

THE GAUGING OF STREAMS.

By CLEMENS HERSCHEL, C. E., Member of the Society.

Read at the Tenth Annual Convention, June 18th, 1878.

All I shall have to say upon the subject of the gauging of streams will be in the nature of two simple suggestions to the Committee, relative to the form in which the records of the gauging of streams should be finally published.

In the first place, as to the measure to be used. We had a paper* not very long ago in the Transactions of the Society on the "Floods of

* See Vol. IV, page 297, December, 1875.

Rivers," and, what to me seemed somewhat curious, the unit chosen was "cubic feet per minute per acre." Now, I think hydraulic writers of eminence are pretty well agreed on one thing—that the unit of measure for running streams should be cubic feet per *second*, and not per *minute*. And they are tolerably agreed also that the *acre* is a rather small area by which to measure drainage areas, and that the *square mile* is much better. And, in fact, the "cubic foot per minute per acre" sounds, to my ears, very much like an importation from Great Britain, which is responsible for a great many very curious and inconvenient dimensions in engineering literature. For one, I hope that "cubic feet per minute per acre" will be banished, and that "cubic feet per second per square mile" will take its place in all these gaugings, to be supplemented and eventually replaced by the cubic meter per second per square kilometer, or the cubic decimeter, or liter, per second per square kilometer, the latter being one thousand times the former. That is one point.

The next point is how, after the quantities are reduced to cubic feet per second per square mile, to portray the flow of a river so that its principal features may be arrived at in a short time. Any one who has ever tried to testify about a river in court, will have noticed, I venture to say, what an awkward thing it is, to describe in a lucid manner. The tendency is to speak of "the six dry months and the six wet months"—of "the six summer months and the six winter months." These begin sometimes in one month and sometimes in another. Oftentimes, beginning with May, the six months following are called the six dry months, and the rest of the year is called the six wet months. But, as you will see from this diagram (which I propose to hand around, because it cannot be seen from the blackboard), there is one diagram, of the Merrimack river, which was constructed for the whole year, [and it is almost perfect], merely from testimony in a certain law-suit relating to what were called the six dry months of the year. This refers to cases tried recently against the City of Boston, where the testimony was given only concerning "the six dry months," beginning with May, and yet among those six dry months, so-called, there is the wettest month in the whole year.

I desire to accompany the statement just made with an explanation. The six months' observations that were given in testimony, I have ar-

ranged, as nearly as I could, in the order they belonged in the whole year, being guided in this task mainly by analogy with the Connecticut river records. Some years the two rivers were almost exactly alike in having such and such months occupy the same places in the order of dryness or wetness. The exact final result is that the diagram given *for the whole year*, and of the Merrimack river, is *probably* nearly correct. On the Connecticut river, May, 1873, was the wettest month in the whole series of forty-eight months, and the other three Mays ranked each next to the wettest month in 1871, '72 and '74. These diagrams very well illustrate that there is really no such thing as "the six dry months" and "the six wet months" of a year, taking them in calendar order. There are, in every year, the six driest and the six wettest months, but they come in no regular order. That brings me to what I was going to say—that the proper way to arrange the months of the year for the purposes of hydraulic engineering is to arrange them, not by their names, and not by their division into seasons, but by this very quality that we are investigating, their wetness and dryness. Let us call the driest month number one; the next driest, be its name what it may, number two, and the wettest will be number twelve.* In that way we may get a diagram which will convey a great deal of meaning to the engineer.

The diagrams accompanying this are drawn for different drainage areas, varying in the numbers of square miles in each, in order to see the effect on the discharge of a river, taking it for a number of years, caused by the size of its drainage area. The diagram indicates in one direction "cubic feet per second per square mile," and in the other direction the relative discharge of the different months in each year. Each year occupies twelve of the horizontal divisions, "one" being the driest, "two" the next driest, "three" the next, until "twelve" is the wettest month of the year. The names of the months are given at each plotted point, so that it may be seen how the wetness and dryness is distributed by months for many years.

The diagram representing the results derived from gaugings of the flow of the west branch of the Croton river is drawn from data given in the paper upon that river, by Mr. J. J. R. Croes, Transactions, Vol. III., p. 76, No. 87. The Sudbury river diagram is founded upon data derived from exact gaugings of that river by the City of Boston, during

* The first suggestion of this method came to me from Mr. Jos. P. Davis, City Engineer of Boston.

the past four or five years. I owe their presentation to kindness of Mr. J. P. Davis, City Engineer, and Mr. A. Fteley his Principal Assistant, in charge of the Additional Supply. The Concord river diagram is drawn from data furnished by accurate gaugings for part of the time, and tolerably accurate ones, controlled by the former, for the rest. This river has figured in so many law-suits in Massachusetts, that a great deal of reliable information has been gathered with regard to it. In 1876 it was gauged every half hour, night and day, for 90 days, by a party of three men, under my charge. Mr. J. P. Frizell, Civil Engineer, late of Boston, has also given me some computations of his own with regard to it. The next diagram, that of the Merrimack river, at Lawrence, is the one that has already been alluded to as being based on data for only six months in each of the years given. The figures used were testified to by Mr. H. F. Mills, of the Essex Company, as being reliable within four per cent., and any one gauging may be either too much or too little by that amount; on the average they must be nearly correct.

The Connecticut river diagram is based upon data given in one of the reports of our member, Gen. Theo. G. Ellis, made to Gen. G. K. Warren, U. S. Engineers, and printed in the report of the Chief of Engineers, U. S. A., for 1875. The drainage area of the Connecticut I have measured on as good a map as I could find of the territory. I think the result is equally reliable with that given concerning the Merrimack river, but both are less reliable than the drainage areas given for the other three rivers.

Of course, it would be somewhat premature to draw conclusions from an inspection of these five diagrams only. The proper time to do this would be after these five rivers, and many more, had been observed for a great number of years, and all these results reduced to diagrams. But certain general conclusions may be stated now, subject to modification, as facts accumulate. Observe, for example, the greater range, each side of a centre line of the curves, drawn in shaded lines, which "*envelope*" the results of the gaugings of the Croton, or of a small water-shed, as compared with the same range as exhibited successively in the diagrams of the other rivers, supplied by larger drainage areas. A decided result is exhibited in the greater discharge per square mile, or *specific* discharge, if that is a proper term, during the driest months of each year of the rivers, with a large water-shed, as compared with those

having only a small one. In fact, there seems to be a regular law about it, the *specific* discharge during the minimum months being proportional to extent of drainage area. It is never below $\frac{1}{2}$ cubic foot per second per square mile in large rivers, while it runs down to less than 0.1 in the smaller rivers shown ; and reckoning for a period of minimum discharge during six working days only, the contrast is still more glaring. These quantities are indicated on the diagrams by a circle under the value for the driest month. Passing to extremes, it will be evident that certain brooks have a minimum discharge, *specific* or otherwise. during a week, equal to 0, while the Merrimack or Connecticut can never fall below $\frac{1}{2}$ cubic foot per second per square mile during the same length of time : a consideration of some importance, frequently, in estimating the value of streams diverted.

One of the uses to which a diagram of the kind presented may be put, is, in estimating the size of the water-wheels it will pay, commercially, to set and attempt to run for any purpose on any given stream. It will not pay, of course, to put in wheels that can be run to their full capacity in the 10th, 11th and 12th wettest month, or in the 11th and 12th only, and which are but partly supplied with water the other 9 or 10 months in the year. In some situations it may pay to attempt to use more of the freshet water than it can in others ; as for instance, when a cotton or woolen mill, which demands a pretty regular supply of power, is combined with other works which may be run with intermissions, such as a mill for grinding dye-stuffs, or a saw-mill, a grist-mill, &c. But with a diagram, such as presented, before him, every engineer can make his calculations for the place under examination and can come to some sort of a rational conclusion about it, while by taking the observations and arranging them by *calendar* months, my experience is, that not so much as a ray of common sense can be made to penetrate the clouds thus formed about the subject. The table below and the diagrams will need no further explanation.

	Croton West Branch, 20½ Sq. M., 3 yrs. observations, 1870-71-72.	Sudbury, at Framingham, 76.3 Sq. M., 3 yrs. observations. 1875-76-77.	Concord, at Lowell, 352 Sq. M., 2 yrs. 7 mos. observations. June, 74-75-76.	Merrimack, at Lawrence. 4136 Sq. M., May to Oct., inclusive. 1871-2-3-4-5-6.	Connecticut, at Hartford, 10 234 Sq. M., 4 yrs. observations, 1871-72-73-74,
	Cubic Feet per Second per Square Mile of Drainage Area.				
Driest 6 working days.	0.04	0.05	0.17	0.53	0.51
Driest month 1	0 29±0.21	0.20±0.10	0.36±0.12	0.68 ±0.08	0.67 ±0.09
2	0.52±0.40	0.32±0.18	0.41±0.13	0.78 ±0.16	0.75 ±0.15
3	0.80±0.60	0.46±0.24	0.45±0.13	0.93 ±0.25	0.86 ±0.20
4	1.10±0.80	0.64±0.30	0.54±0.16	1.11 ±0.36	1.01 ±0.29
5	1.45±1.00	0.83±0.33	0.67±0.19	1.34 ±0.46	1.21 ±0.39
6	1.85±1.20	1.08±0.38	0.85 ±0.25	1.59 ±0.59	1.48 ±0.52
7	2.30±1.40	1.36±0.42	1.10 ±0.35	1.88 ±0.73	1.76 ±0.64
8	2.85±1.50	1.70±0.46	1.35 ±0.40	2.20 ±0.85	2.09 ±0.75
9	3.50±1.65	2.14±0.56	1.70 ±0.50	2.68 ±0.93	2.51 ±0.87
10	4.20±1.80	2.75±0.80	2.10 ±0.60	3.30 ±1.05	3.08 ±0.93
11	5.05±1.95	3.80±1.35	2.65 ±0.75	4.10 ±1.25	4.00 ±1.10
12	6.65±1.35	6.00±1 50	4.30 ±1.10	5.80 ±1.00	5.85 ±1.05
Max. freshet known.		41.60 Mch. 26, 1876	12.64 Mch. 29–30, 1876.	23.4 In 1852.	20.27 May, 1854.

Addenda.

Since the above paper was written, the U. S. Corps of Engineers have published the gaugings of the Connecticut river for 1875, '76, and '77. I have calculated the corresponding discharges in cubic feet per second, and in cubic feet per second per square mile of drainage area; and arranged the months of each year in their order of amount discharged, or, as it has been called, in their order of dryness. If the data for these three years be plotted on the diagram, it will be seen that they fit very well into the limits marked out from the data of the years 1871 to '74, which alone were available when the diagram was made.

Discharge of the Connecticut River at Hartford—10,234 Square Miles of Drainage Area.

Order of dryness.	Month.	Cubic feet per second.	Cubic feet per second per square mile.
	1875.		
1	Jan.....	6 376	0.62
2	Sept.....	6 739	0.66
3	July.....	8 584	0.84
4	Oct.....	10 225	1.00
5	Feb.....	11 170	1.09
6	Aug.....	11 937	1.17
7	June.....	13 737	1.34
8	Nov	15 827	1.55
9	Dec.....	16 272	1.59
10	March.....	18 307	1.79
11	May	41 606	4.07
12	April.....	56 346	5.51
	1876.		
1	Aug.....	6 225	0.61
2	Oct.....	6 321	0.62
3	Dec.....	6 405	0.63
4	Sept.....	6 630	0.65
5	Nov	8 033	0.78
6	July.....	8 240	0.80
7	June.....	15 821	1.55
8	Feb.....	25 407	2.48
9	Jan.....	29 852	2.92
10	March.. ...	35 045	3.42
11	May.....	58 065	5.67
12	April.....	62 020	6.06
	1877.		
1	Jan.....	6 534	0.64
2	Sept.....	6 979	0.68
3	Feb.....	7 643	0.75
4	June.....	8 066	0.79
5	Aug.....	8 567	0.84
6	July.....	9 511	0.93
7	Oct.....	11 862	1.16
8	May.....	16 941	1.65
9	Dec.....	17 317	1.69
10	Nov.....	29 254	2.86
11	March.....	34 817	3.40
12	April.....	42 533	4.16

Lowest 6 Working Days.

1875.. Jan. 25-30.....	6 238	0.61
1876.. Aug. 28—Sept. 2....	5 660	0.55
1877.. Jan. 1-6.....	5 937	0.58